

is only necessary, therefore, to be able to count the number of graduations which pass in that period. As a perfectly uniform rotation has not been obtained, a regulator under the control of the operator is employed. This consists merely of a piece of string which passes round the axis of the drum, and also round a pulley which can be turned by the operator's left hand. An upward or downward motion of the wave denotes that the drum is going too fast or too slow, and by means of the pulley a gentle check or acceleration sufficient to keep the wave steady is given to the drum.

An electric counter gives the number of complete revolutions accomplished by the drum in any given period, and a fine-pointed tube, containing magenta, is carried by a saddle above the drum, and being actuated by an electro-magnet, makes a dot on a piece of white paper wrapped round the drum at the beginning and end of the experiment. The distance apart of these dots gives the additional fraction of a revolution accomplished by the drum during the period of the experiment. Electric circuits are so arranged that a reverser turned a few seconds before the minute at which it is intended to begin the experiment, causes a current to be sent exactly at that minute by the clock relay, which starts the electric counter, and also makes a dot on the drum. Just before the expiration of the last minute of the experiment, the reverser is turned in the opposite direction, and at the expiration of that minute the counter is stopped, and a second mark made on the drum.

Some of the results obtained with different forks are given.

The results of further experiments made to determine the effect of temperature, of continuous and intermittent bowing, and of the mode of fixing the fork are appended.

An optical method by which two slightly dissonant forks may be compared without altering the period of either, is described.

Figures and diagrams fully explaining the apparatus employed, accompany the paper.

IV. "On certain means of Measuring and Regulating Electric Currents." By C. WILLIAM SIEMENS, D.C.L., F.R.S. Received January 16, 1879.

[PLATES 4, 5.]

The dynamo-electric machine furnishes us with a means of producing electric currents of great magnitude, and it has become a matter of importance to measure and regulate the proportionate amount of current that shall be permitted to flow through any branch circuit, especially in such applications as the distribution of light and mechanical force.

On the 19th of June last, upon the occasion of the Soirée of the President of the Royal Society, I exhibited a first conception of an arrangement for regulating such currents, which I have since worked out into a practical form. At the same time, I have been able to realize a method by which currents passing through a circuit, or branch circuit, are measured, and graphically recorded.

It is well known that when an electric current passes through a conductor, heat is generated, which, according to Joule, is proportionate in amount to the resistance of the conductor, and to the square of the current which passes through it in a unit of time, or

$$H = C^2 R.$$

I propose to take advantage of this well-established law of electrodynamics, in order to limit and determine the amount of current passing through a circuit, and the apparatus I employ for this purpose is represented on figs. 1 to 3, Plate 4, of the accompanying drawings. Letters of reference to the principal parts of the instrument are given on the foot-note of the drawing.

The most essential part of the instrument is a strip (A) of copper, iron, or other metal, rolled extremely thin, through which the current to be regulated has to pass. One end of this thin strip of metal is attached to a screw (B), by which its tension can be regulated; it then passes upwards over an elevated insulated pulley (I), and down again to the end of a short lever, working on an axis, armed with a counterweight and with a lever (L), whose angular position will be materially affected by any small elongation of the strip that may take place from any cause. The apparatus further consists of a number of prisms of metal (P), supported by means of metallic springs (M), so regulated by movable weights (W) as to insure the equidistant position of each prism from its neighbour, unless pressed against the neighbouring piece by the action of the lever (L), in consequence of a shortening of the metallic strip. By this action, one prism after another would be brought into contact with its neighbour, until the last prism in the series would be pressed against the contact spring (S), which is in metallic connexion with the terminal (T).

The current passing through the thin strip of metal will, under these circumstances, pass through the lever (L) and the line of prisms to the terminal (T), without encountering any sensible resistance. A second and more circuitous route is, however, provided between the lever (L) and the terminal (T), consisting of a series of comparatively thin coils of wire of German silver or other resisting metal (R, R), connecting the alternate ends of each two adjoining springs, the first and last spring being also connected to the lever (L) and terminal (T) respectively.

When the lever (L) stands in its one extreme position, as shown in

the drawing, the contact pieces are all separate, and the current has to pass through the entire series of coils, which present sufficient aggregate resistance to prevent the current from exceeding the desired limit.

When the minimum current is passing, the thin metallic strip is at its minimum working temperature, and all the metallic prisms are in contact, this being the position of least resistance. As soon as the current passing through the apparatus shall increase in amount, the thin metallic strip will immediately rise in temperature, which will cause it to elongate, and will allow the lever (L) to recede from its extreme position, liberating one contact piece after another. Each such liberation will call into action the resistance coil connecting the spring ends, and an immediate corresponding diminution of the current through increased resistance; additional resistance will thus be thrown into the circuit, until an equilibrium is established between the heating effect produced by the current in the sensitive strip, and the diminution of heat by radiation from the strip to surrounding objects. In order to obtain uniform results, it is clearly necessary that the loss of heat by radiation should be made independent of accidental causes, such as currents of air or rapid variations of the external temperature, for which purpose the strip is put under a glass shade, and the instrument itself should be placed in a room where a tolerably uniform temperature of say 15°C . is maintained. Under these circumstances, the rate of dissipation by radiation and conduction (considering that we have to deal with low degrees of heat) increases in arithmetical ratio with the temperature of the strip; the expansion of the strip, which affects the position of the lever (L), is proportionate to the temperature which is itself proportionate to the square of the current—a circumstance highly favourable to the sensitive action of the instrument.

Suppose that the current intended to be passed through the instrument is capable of maintaining the sensitive strip at a temperature of say 60°C ., and that a sudden increase of current takes place in consequence either of an augmentation of the supply of electricity or of a change in the extraneous resistance to be overcome, the result will be an augmentation of temperature, which will continue until a new equilibrium between the heat supplied and that lost by radiation is effected. If the strip is made of metal of high conductivity, such as copper or silver, and is rolled down to a thickness not exceeding 0.05 milim., its capacity for heat is exceedingly small, and its surface being relatively very great, the new equilibrium between the supply of heat and its loss by radiation is effected almost instantaneously. But, with the increase of temperature, the position of the regulating lever (L) is simultaneously affected, causing one or more contacts to be liberated, and as many additional resistance coils to be thrown

into circuit: the result being that the temperature of the strip varies only between very narrow limits, and that the current itself is rendered very uniform, notwithstanding considerable variation in its force, or in the resistance of the lamp, or other extraneous resistance which it is intended to regulate.

It might appear at first sight that, in dealing with powerful currents, the breaking of contacts would cause serious inconvenience in consequence of the discharge of extra current between the points of contact. But no such discharges of any importance actually take place, because the metallic continuity of the circuit is never broken, and each contact serves only to diminish to some extent the resistance of the regulating rheostat. The resistance coils, by which adjoining contact springs are connected, may be readily changed, so as to suit particular cases; they are made by preference of naked wire, in order to expose the entire surface to the cooling action of the atmosphere.

In dealing with feeble currents, I use another form of regulator, in which disks of carbon are substituted for the wire rheostat. The Count du Moncel, in 1856, first called attention to, and Mr. Edison more recently took advantage of, the interesting circumstance that the electrical resistance of carbon varies inversely with the pressure to which it is subjected, and by piling several disks of carbon one upon another in a vertical glass tube, a rheostat may be constructed which varies between wide limits, according as the mechanical pressure in the line of the axis is increased or diminished. Fig. 4, Plate 5, represents the current regulator based upon this principle, and the foot-notes below the figure furnish the explanation of parts. A steel wire of say 0.3 milim. diameter is drawn tight between the end of a bell-crank lever (L) and an adjusting screw (B), the pressure of the lever being resisted by a pile of carbon disks (C) placed in a vertical glass tube. The current passing through the steel wire, through the bell-crank lever, and through the carbon disks, encounters the minimum resistance in the latter so long as the tension of the wire is at its maximum; whereas the least increase in temperature of the steel wire by the passage of the current causes a decrease of pressure upon the pile of carbon disks, and an increase in their electrical resistance; it will thus be readily seen that, by means of this simple apparatus, the strength of small currents may be regulated so as to vary only within certain narrow limits.

The apparatus described in figs. 1 to 3, Plate 4, may be adapted also for the *measurement* of powerful electric currents—an application which is represented by figs. 5 and 6, Plate 5. The variable rheostat is in this case dispensed with, and the lever (L) carries at its end a pencil (P) pressing with its point upon a strip of paper drawn under it in a parallel direction with the lever by means of clockwork. A second fixed pencil (D) draws a second or datum line upon the strip, so

adjusted that the lines drawn by the two pencils coincide when no current is passing through the sensitive strip. The passage of a current through the strip immediately causes the pencil attached to the lever to move away from the datum line, and the distance between the two lines represents the temperature of the strip. This temperature depends, in the first place, upon the amount of current passing through the strip, and, in the second place, upon the loss of heat by radiation from the strip; which two quantities balance one another during any interval that the current remains constant.

If C is the current before increase of temperature has taken place;

R the resistance of the conductor at the external temperature (T);

H the heat generated per unit of time at the commencement of the flow;

R' the resistance, and H' the heat, when the temperature T' and the current C' have been attained;

Then by the law of Joule—

$$H' = R'C'^2.$$

But inasmuch as the radiation during the interval of constant current and temperature is equal to the supply of heat during the same interval, we have by the law of Dulong and Petit—

$$H' = (T' - T)S,$$

in which S is the radiating surface. Then

$$R'C'^2 = (T' - T)S$$

$$C'^2 = (T' - T) \frac{S}{R'}.$$

But $T' - T$ represents the expansion of the strip, or movement of the pencil m , and considering that the electrical resistance of the conductor varies as its absolute temperature (which upon the Centigrade scale is 274° below the zero Centigrade) according to a law first expressed by Helmholtz, and that we are only here dealing with a few degrees difference of temperature, no sensible error will be committed in putting the value of R for R' , and we have the condition of equilibrium

$$C'^2 = m \frac{S}{R} \therefore C' = \sqrt{m \frac{S}{R}}, \quad (1)$$

or, in words, the current varies as the square root of the difference of temperature or ordinates.

For any other condition of temperature T'' we have

$$C''^2 = \frac{S}{R}(T'' - T)$$

$$\therefore C'' = \sqrt{\frac{S}{R}(T'' - T)}.$$

Siemens.

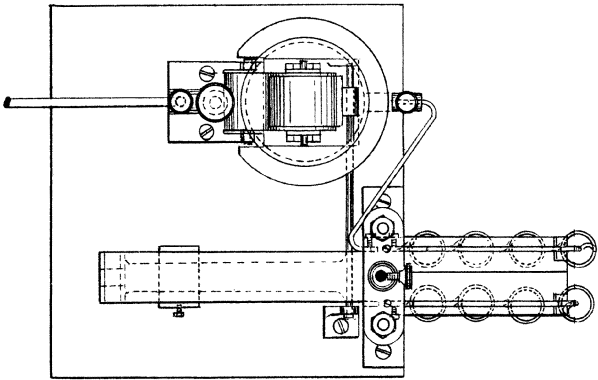


Fig. 3.

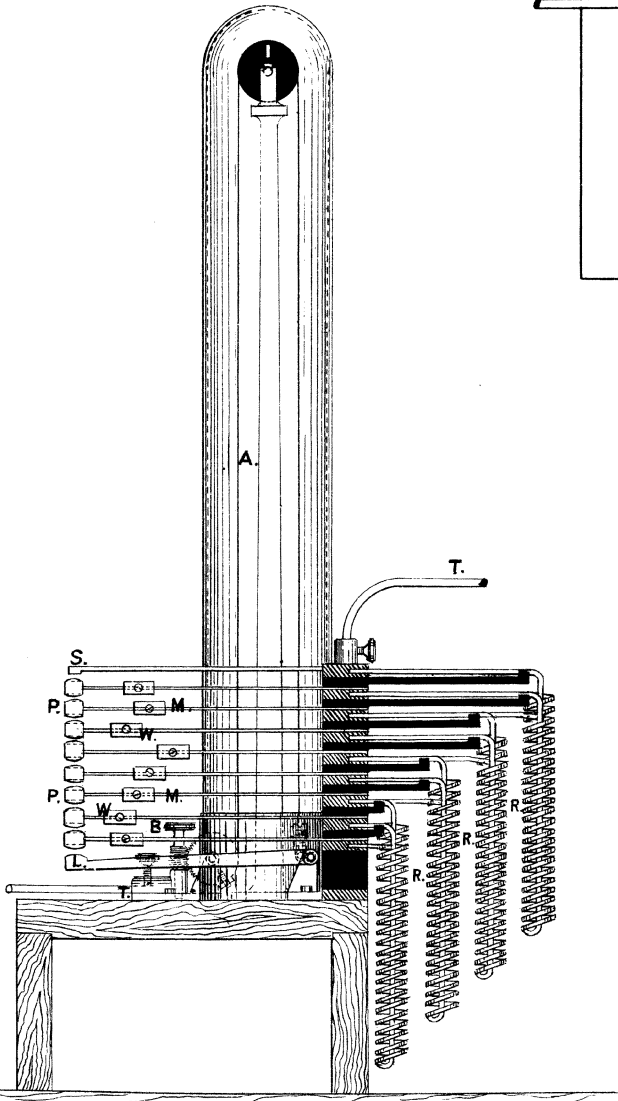


Fig. 1.

- A.— Sensitive strip.
- B.— Tension screw.
- L.— Lever.
- M.— Metal springs
- I.— Insulated pulley.
- W.— Adjusting weights.
- P.— Contact prisms.
- S.— Contact spring.
- T.— Terminal.
- R.— Resistance coils.

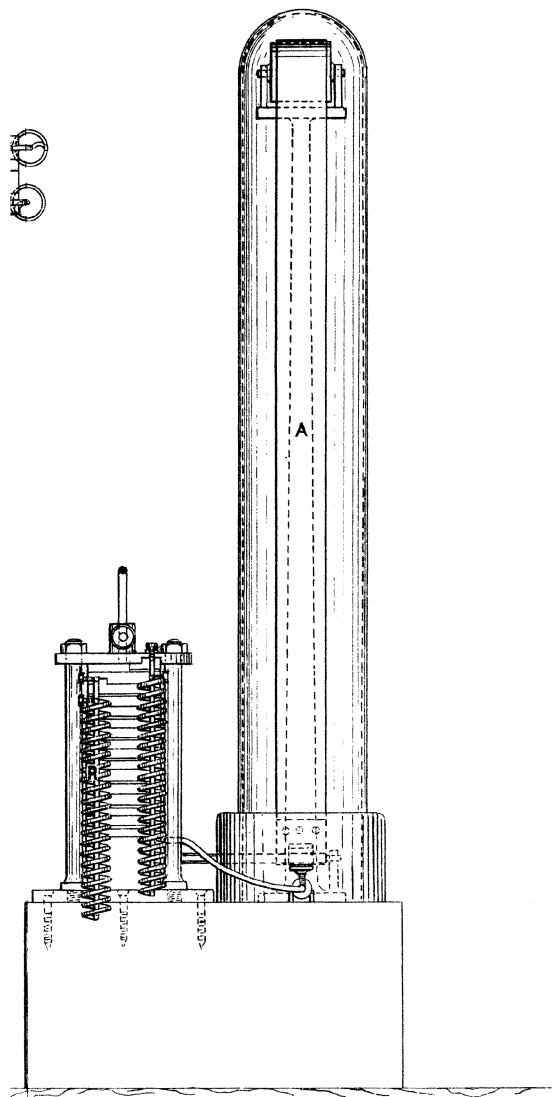


Fig. 2.

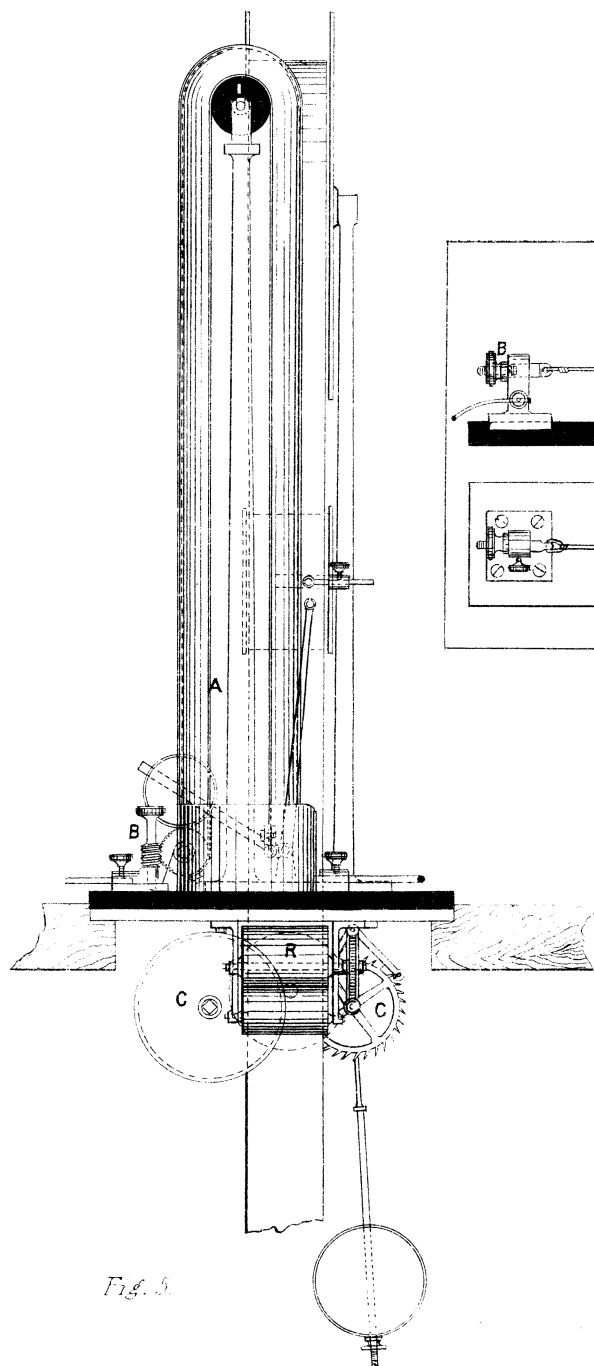


Fig. 5.

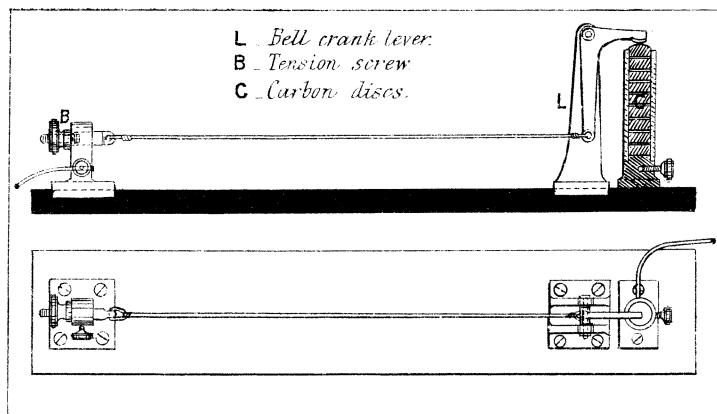


Fig. 4.

- A. — Sensitive strip.
- B. — Tension screw.
- I. — Insulated pulley.
- L. — Lever.
- D. — Datum pencil.
- P. — Movable pencil.
- C. — Clockwork.
- R. — Friction rollers.

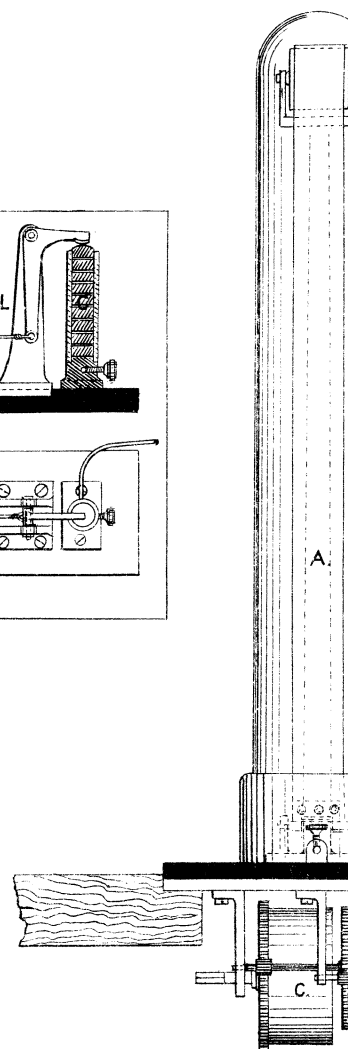


Fig.

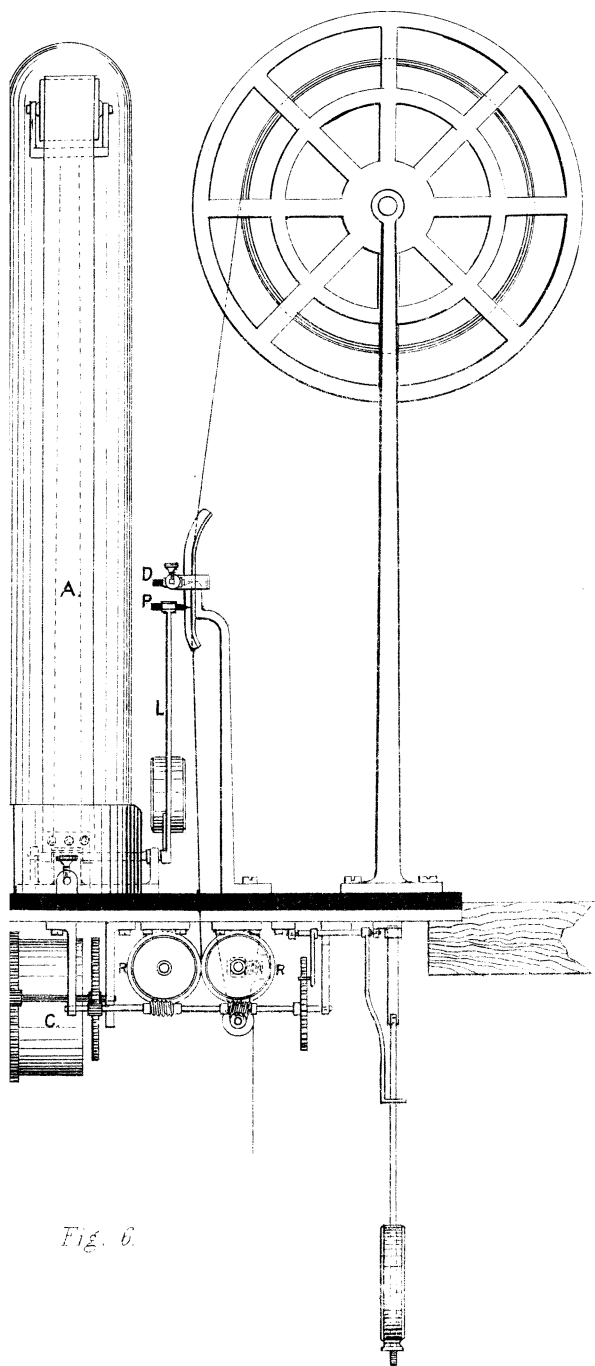


Fig. 6.

$$\text{and } (C''^2 - C'^2) = (T'' - T - T' + T) \frac{S}{R} = (T'' - T') \frac{S}{R},$$

but for small differences of C'' and C' we may put

$$(C''^2 - C'^2) = 2C''(C'' - C'),$$

that is to say, small variations of current will be proportional to the variation in the temperature of the strip.

In order to facilitate the process of determining the value of a diagram in webers or other units of current, it is only necessary, if the variations are not excessive, to average the ordinates, and to determine their value by equation (1), or from a table prepared for that purpose. The error committed in taking the average ordinate instead of the absolute ordinates, when the current varies between small limits, is evidently small, the variation of the ordinates above their mean value averaging the variations below the same.

The thin sensitive conductor may thus be utilized either to restrict the amount of electricity flowing through a branch circuit within certain narrow limits, or to produce a record of the amount of current passed through a circuit in any given time.

Presents, January 9, 1879.

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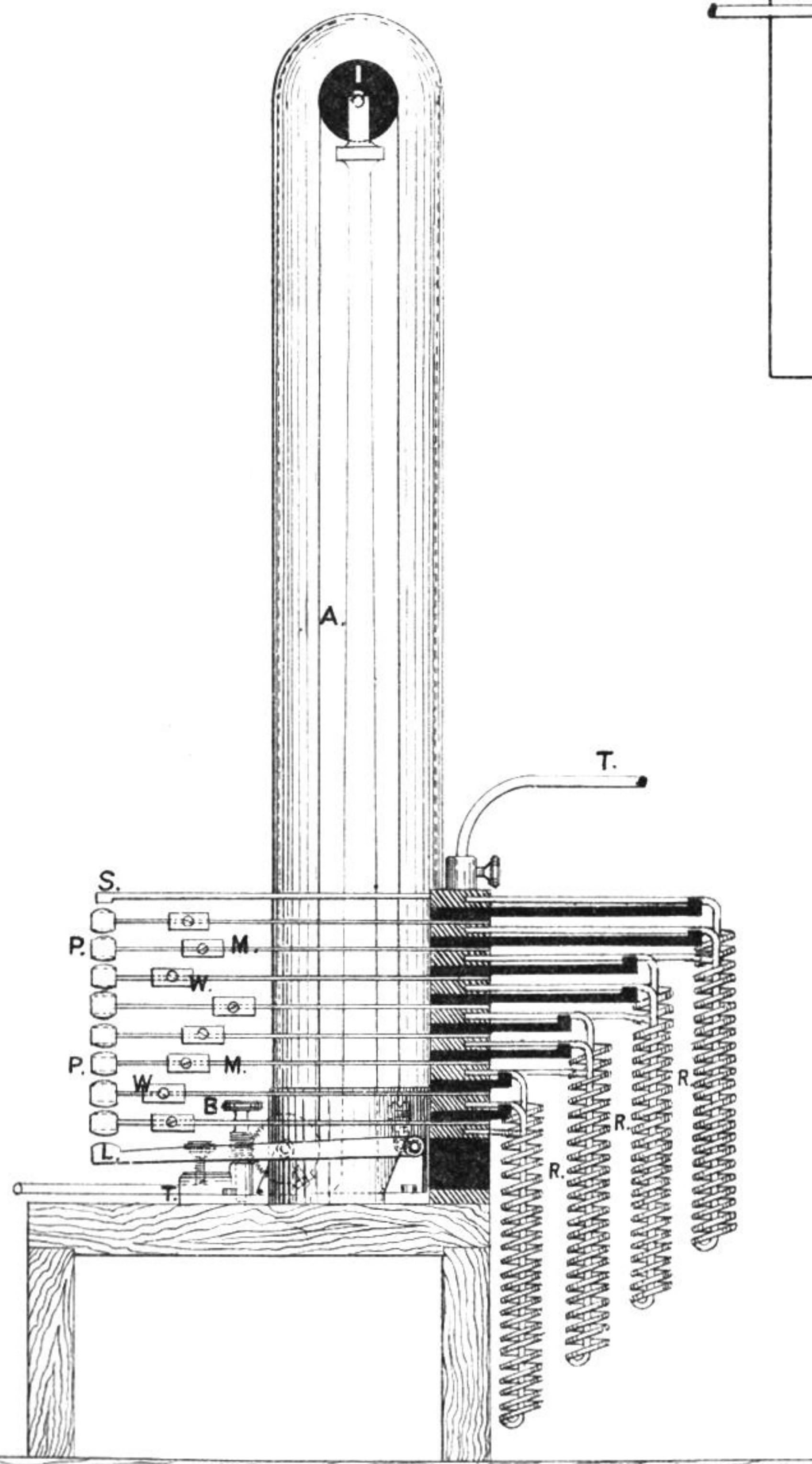


Fig. 1.

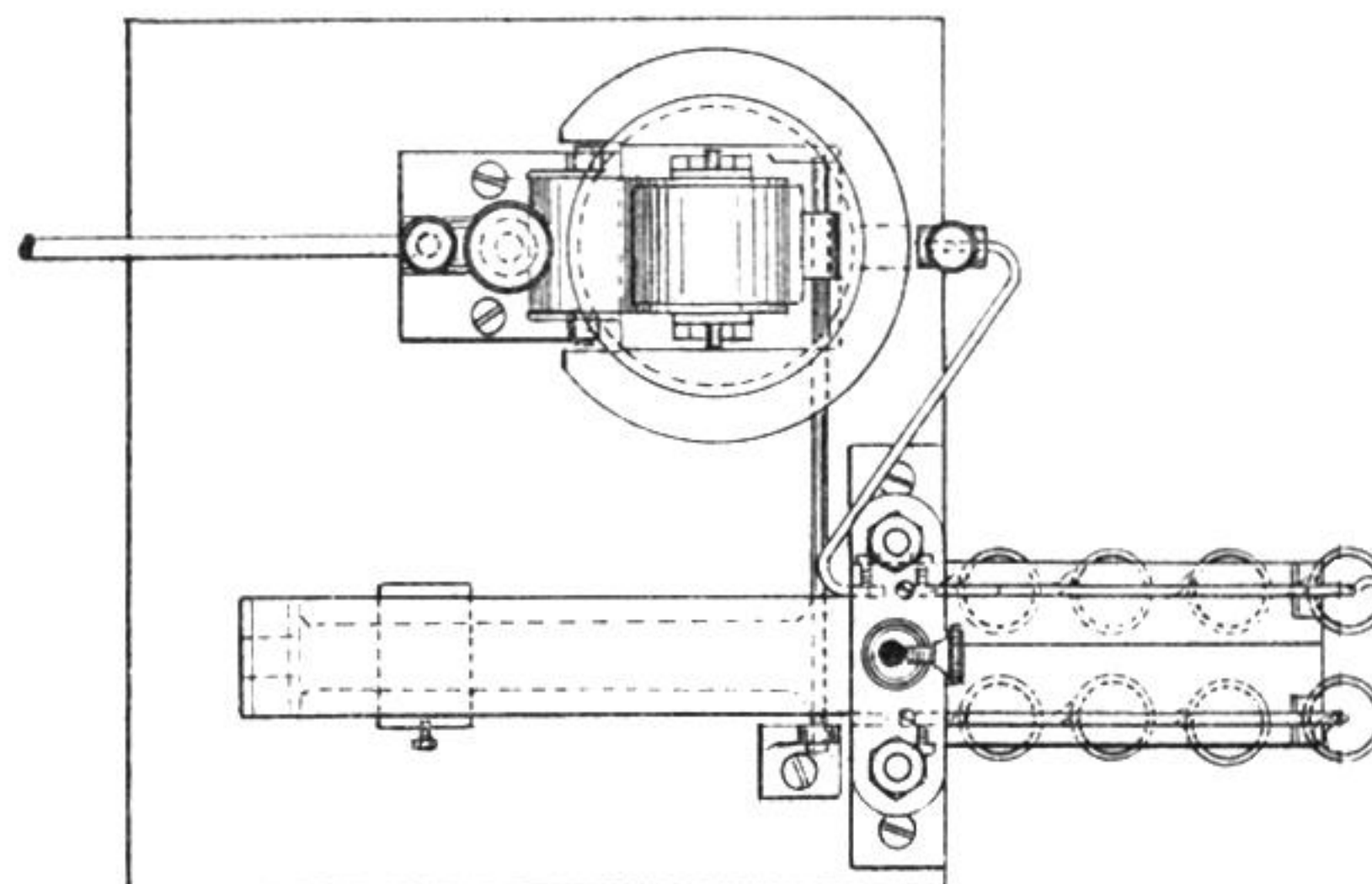


Fig. 3.

- A.— Sensitive strip.
 B.— Tension screw.
 L.— Lever.
 M.— Metal springs
 I.— Insulated pulley.
 W.— Adjusting weights.
 P.— Contact prisms.
 S.— Contact spring.
 T.— Terminal.
 R.— Resistance coils.

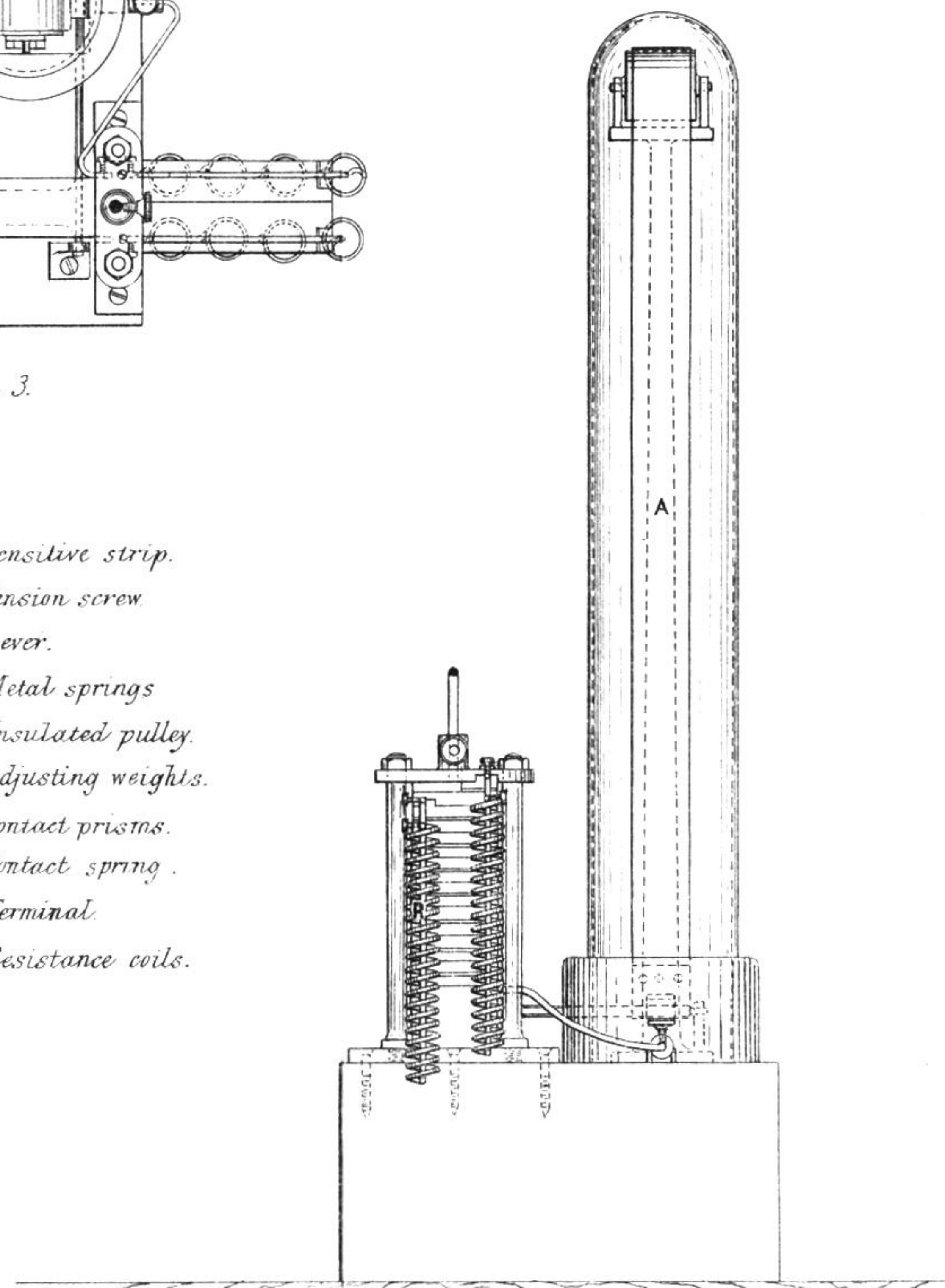


Fig. 2.

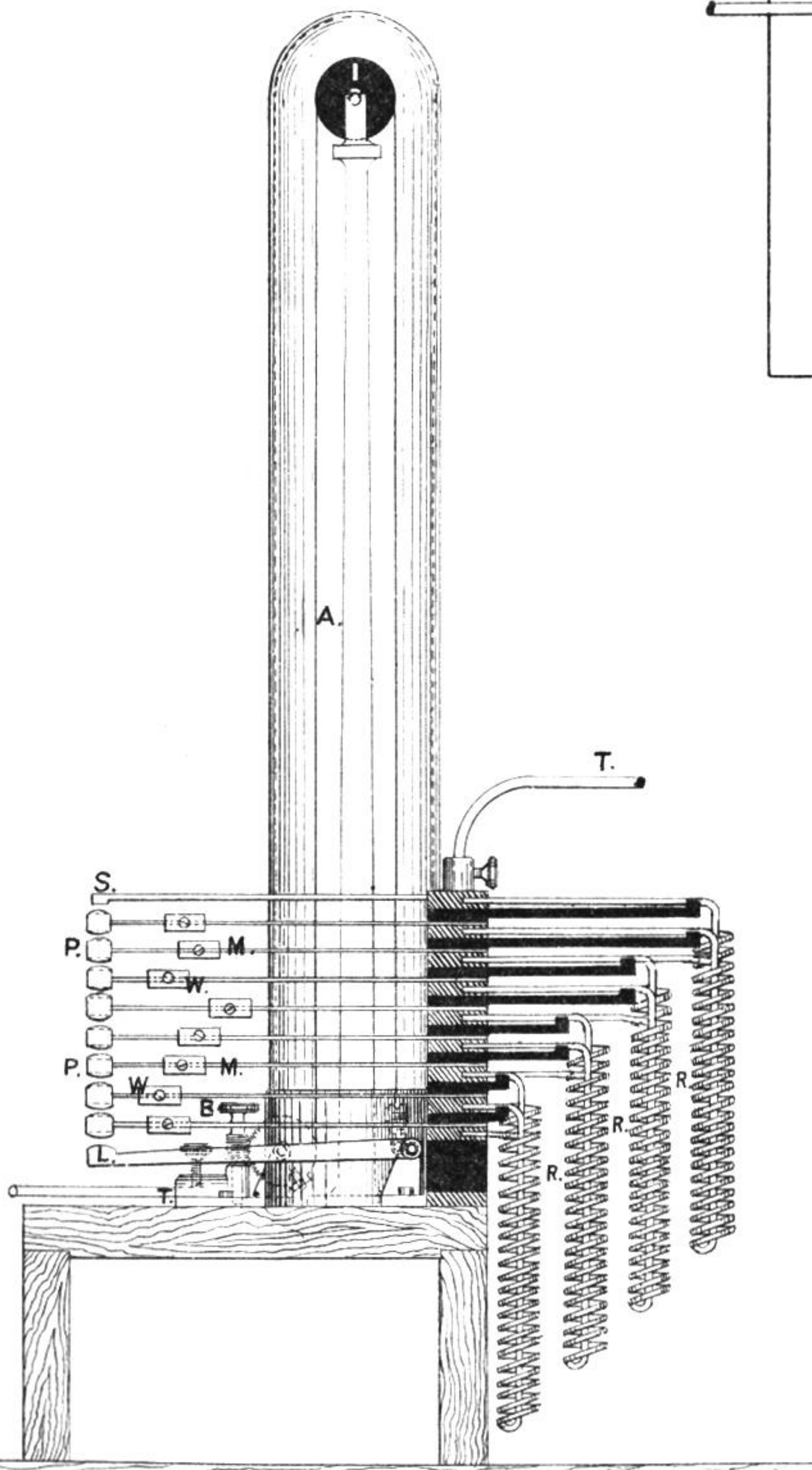


Fig. 1.

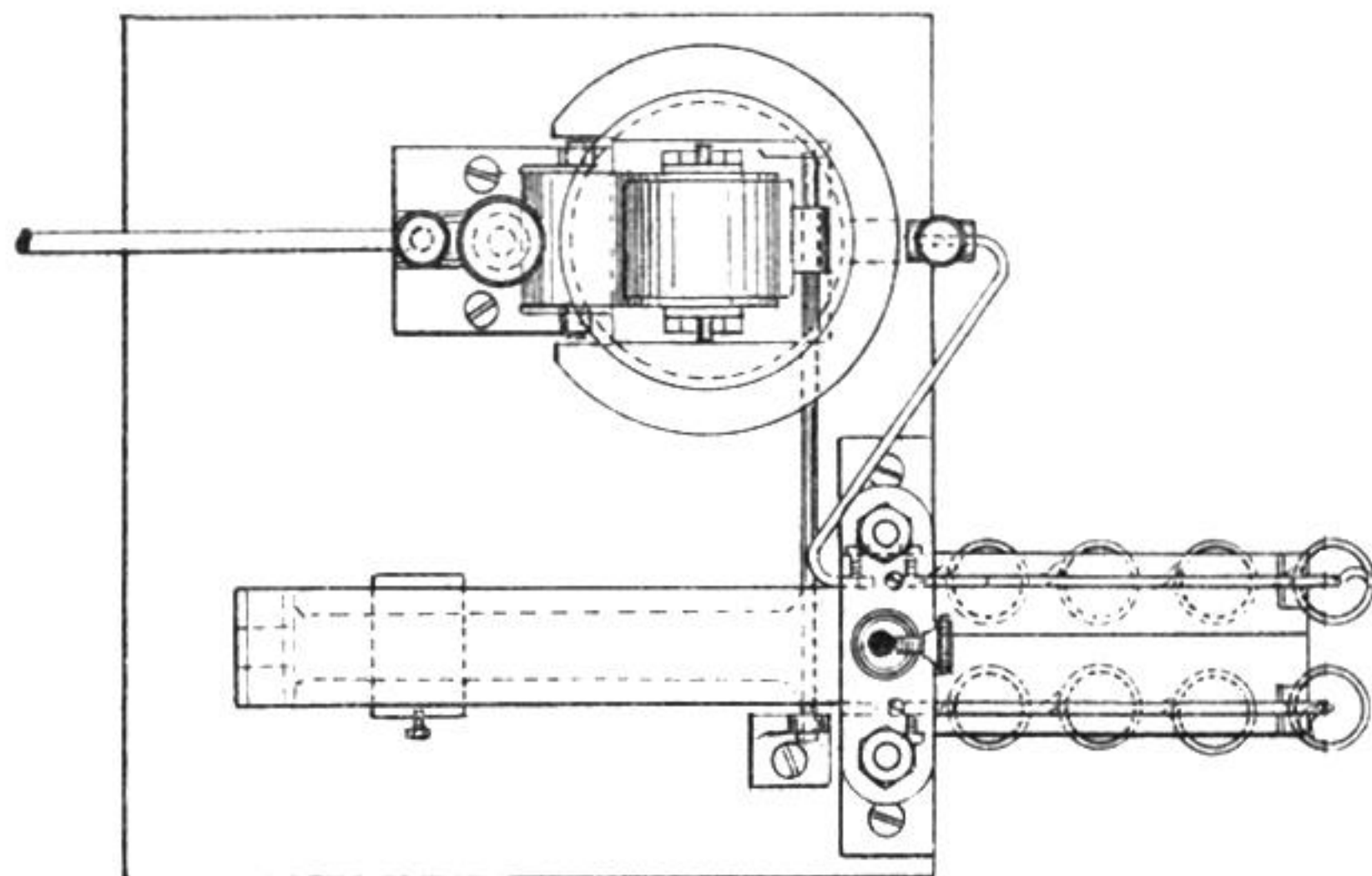


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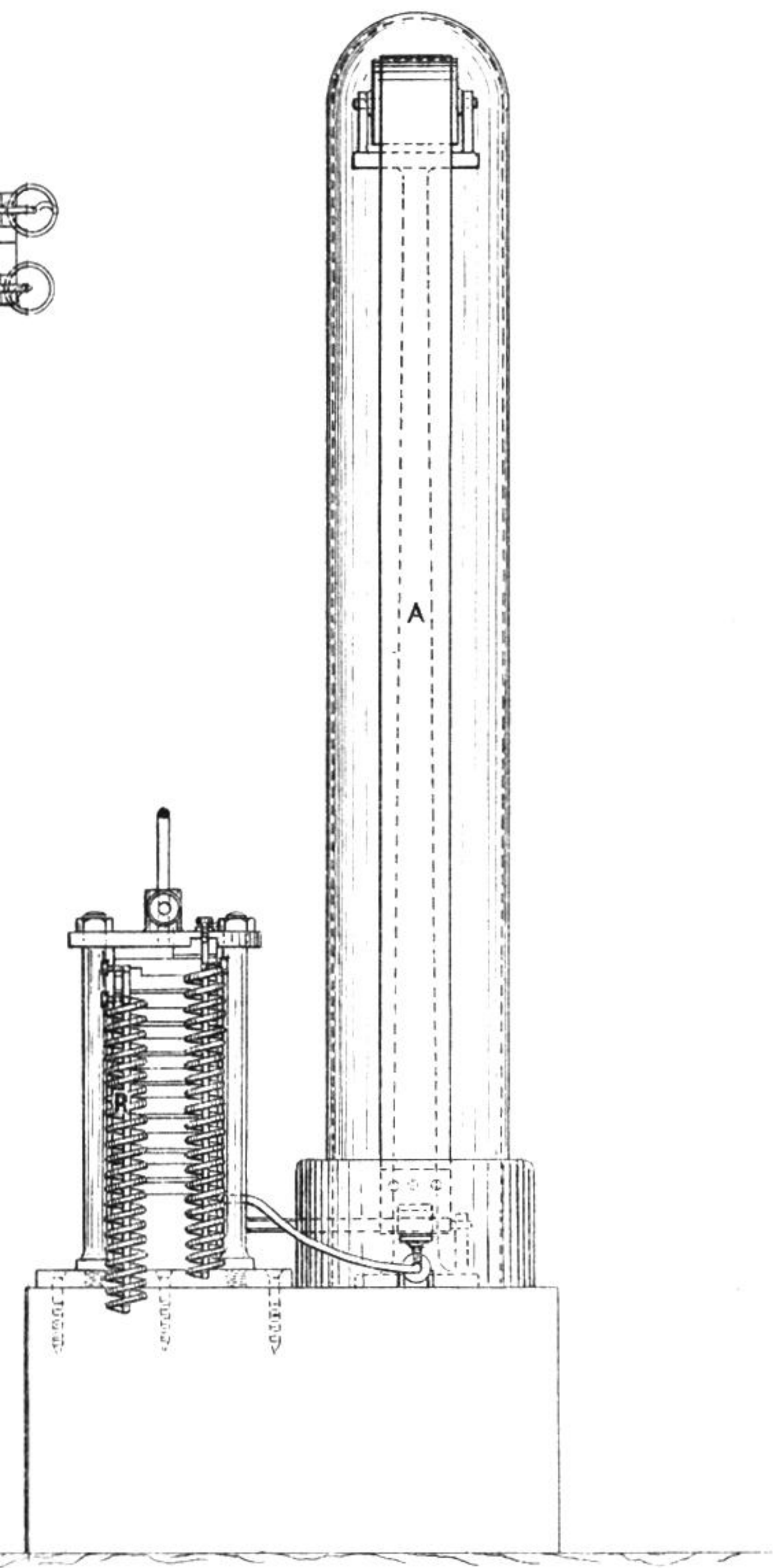


Fig. 2.

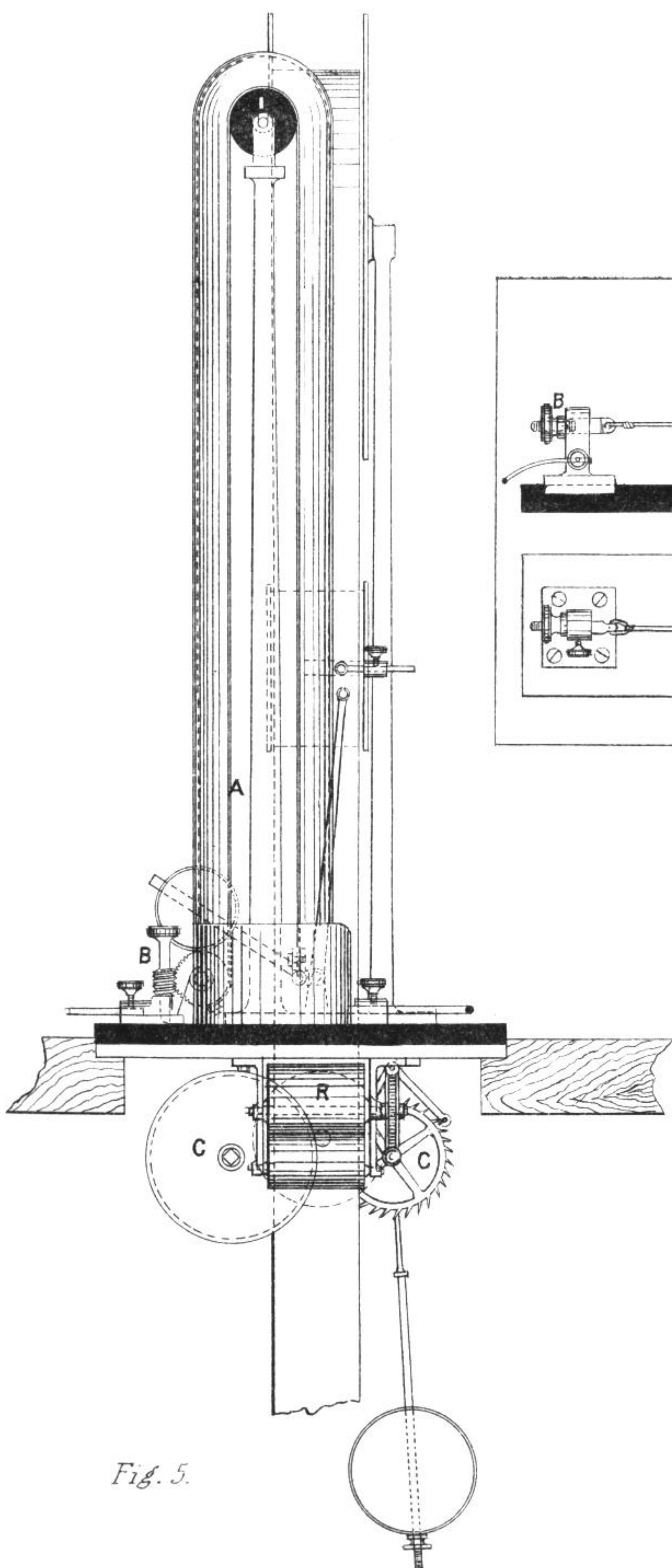


Fig. 5.

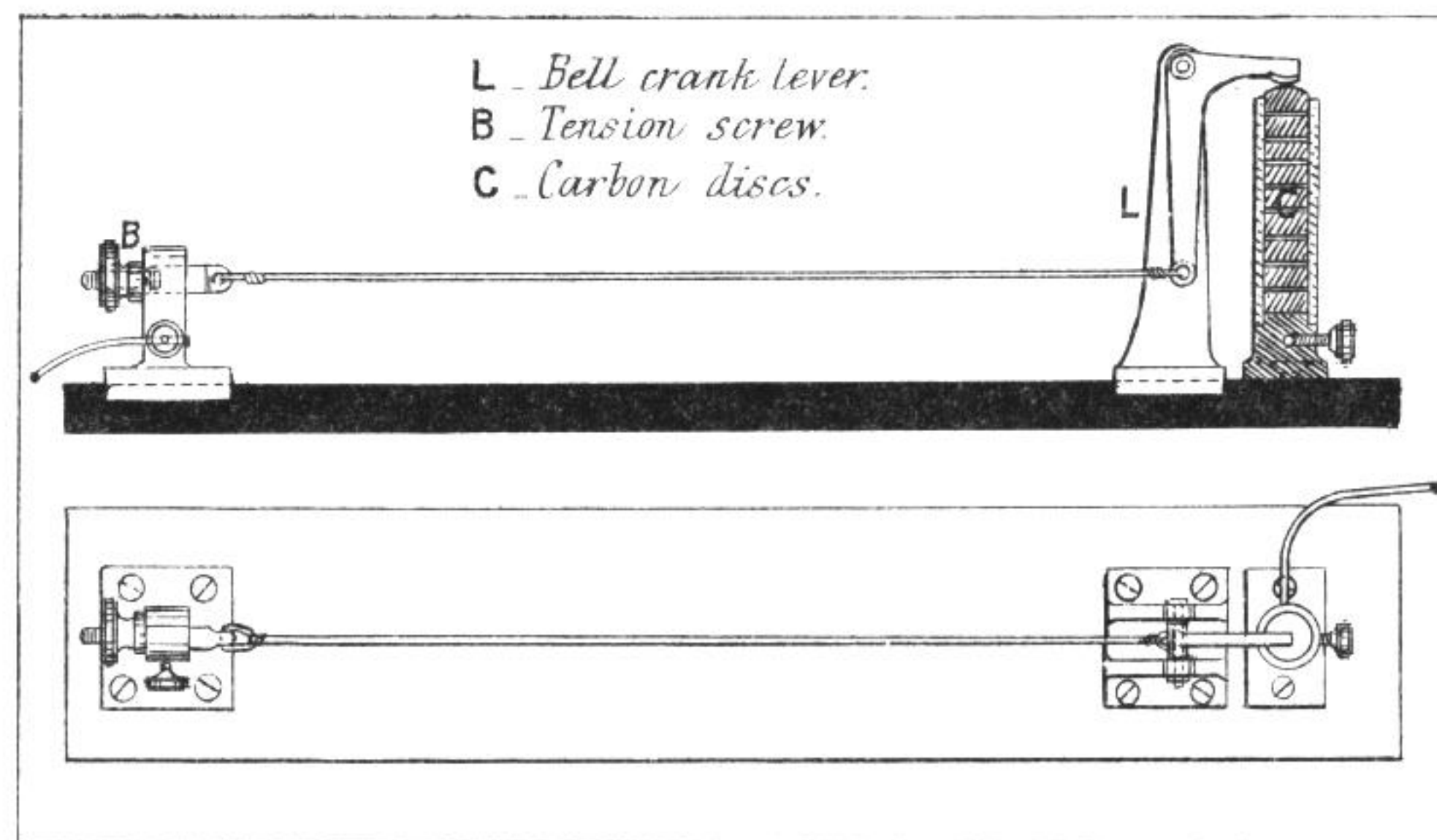


Fig. 4.

- A. — Sensitive strip.
- B. — Tension screw.
- I. — Insulated pulley.
- L. — Lever.
- D. — Datum pencil.
- P. — Movable pencil.
- C. — Clockwork.
- R. — Friction rollers.

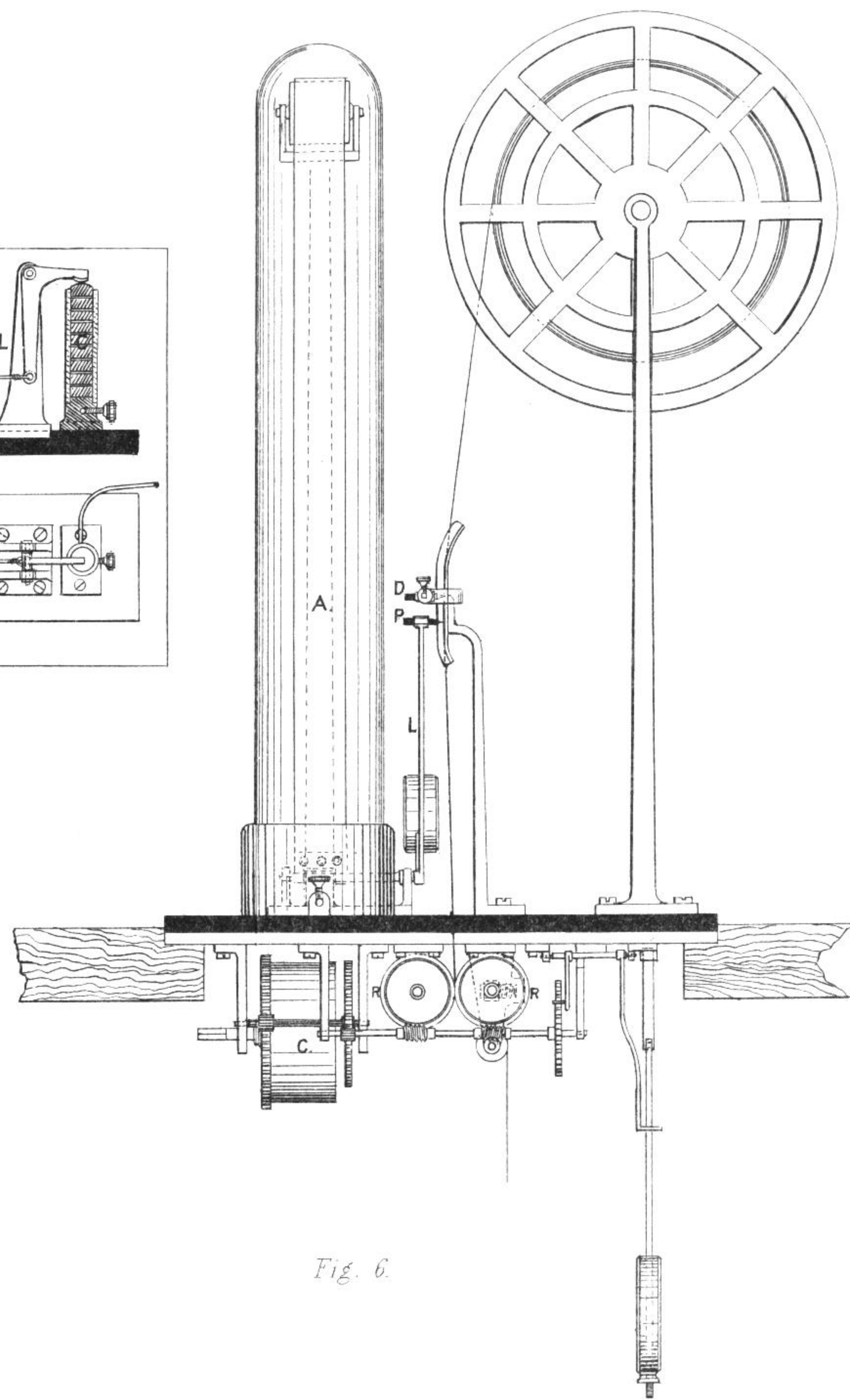


Fig. 6.

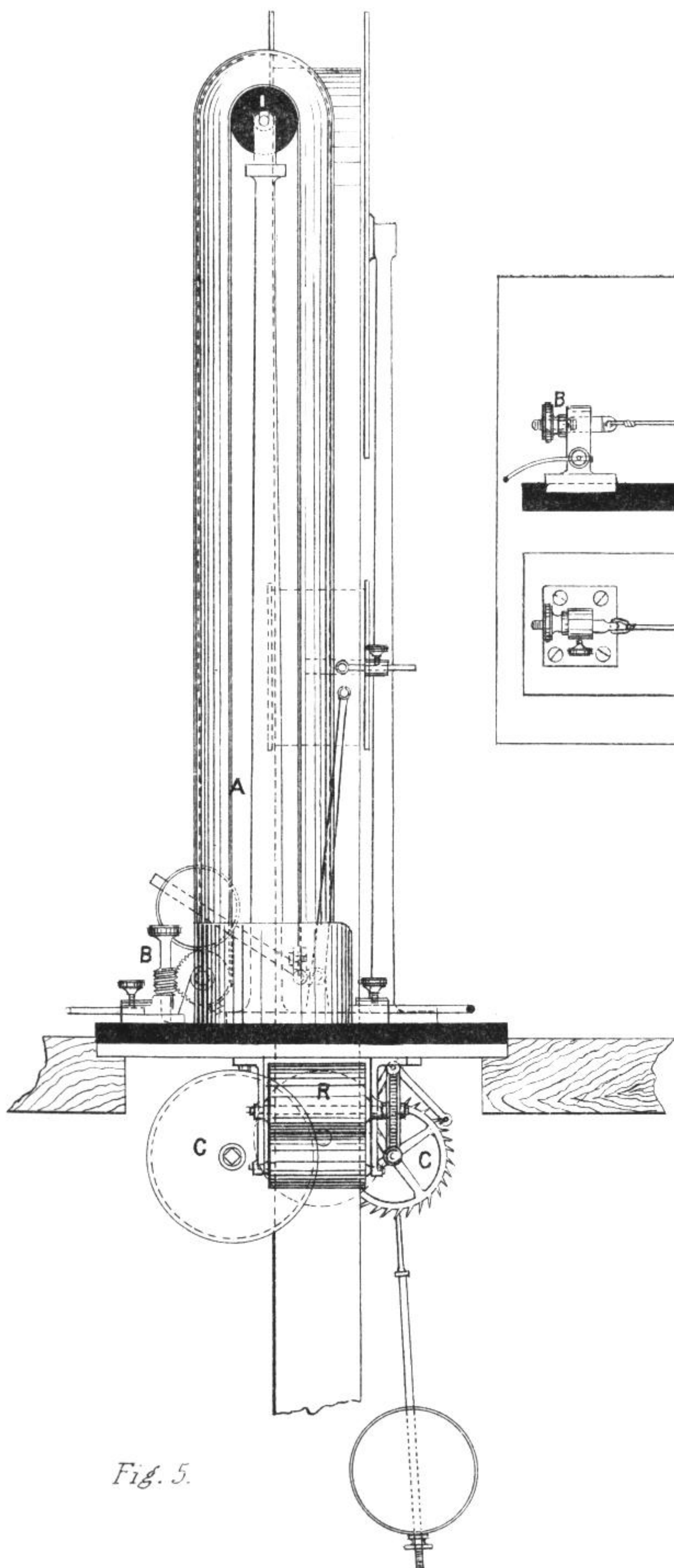


Fig. 5.

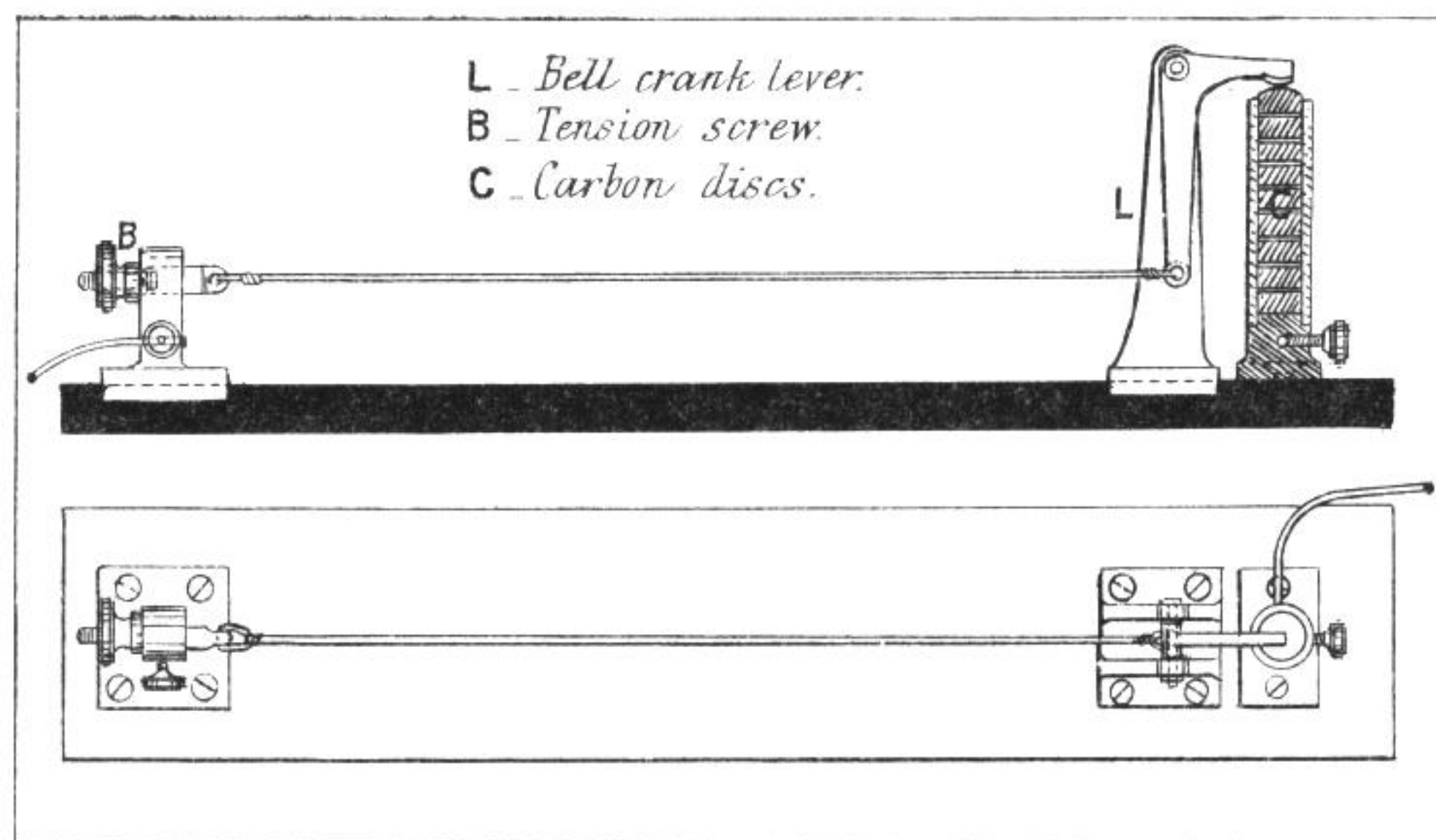
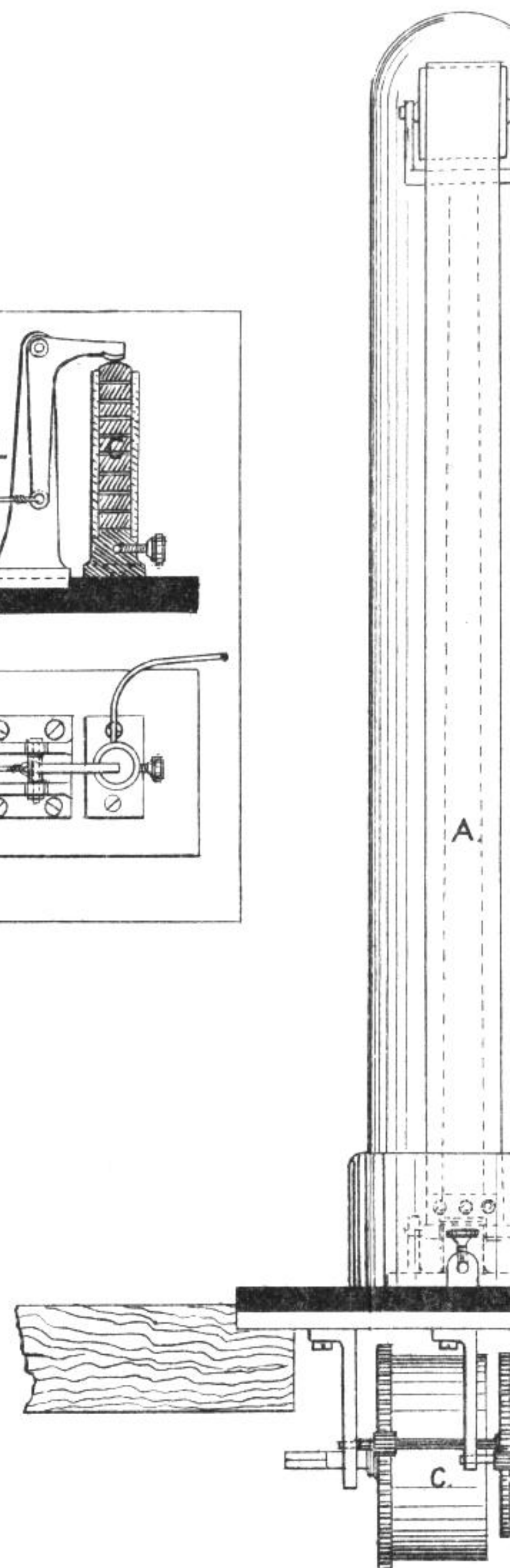


Fig 4.



Fig

- A. — Sensitive strip.
- B. — Tension screw.
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